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A model for the assessment of the animal disease risks associated with the importation of animals and animal products

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***Summary**: A simple mathematical model to assess the disease risks associated with the importation of animals and animal products is presented. This model is dependent on the animal health and disease statistics reported by the Member Countries of the Office International des Epizooties (OIE), and provides a structured approach to using information about a particular importation. The model can incorporate any number of determinants; these may be related to the animal health status of the exporting country, the commodity (whether animal or animal product), the properties of the disease agent and the epidemiology of the disease. All disease risks can be considered. Examples illustrate the model with respect to the importation of cattle, swine and related products.*

KEYWORDS: Animal importation - Model - OIE Lists A and B diseases - Prevalence - Risk assessment.

INTRODUCTION

The importation of animals and animal products always involves a degree of disease risk for the importing country. One or several diseases make up this disease risk. Regulatory officials responsible for import programmes require an objective, repeatable and defensible method of assessing these risks. Because multiple disease entities are involved in each import decision, the method must be easy to apply. The risk assessment output must be straightforward and transparent to every party influenced by the import decision. The demand for the importation of a large variety of animal products requires a rapid process. However, more importantly, the method employed must not jeopardize the health status of the importing country.

The exclusion of an animal, animal product or by-product due solely to the presence of a disease in an exporting country is no longer a defensible policy. Application of such a policy would ignore the progress which countries have made in the control and confinement of a disease, and fails to consider the competency of the Veterinary Services in ensuring a safe product. A policy of exclusion ignores the survivability of disease agents within products, the modes of transmission of disease and the means of exposure of the disease in the importing country.

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A risk assessment is dependent on information. This includes such data as the disease status of the exporting country, the nature of the disease hosts, the modes of transmission, the vectors, persistence of infection, and agent survival in animal products and by-products. The accuracy of the animal disease statistics depends on the competency of the Veterinary Services and the disease surveillance system. The confinement of a disease to a particular area is important, as the animals and animal products for export may originate exclusively from disease-free regions or zones. Therefore, it is understandable that importing countries consider not only risk assessment in import decision-making but also the assessment of the Veterinary Services, disease surveillance systems and disease regionalization or zoning programmes.

The objective of this paper is to portray a quantitative risk assessment method to assess the likelihood of disease risks associated with animal or animal product importation. This method is dependent on the animal disease statistics reported by the Member Countries of the Office International des Epizooties (OIE).

DEFINITIONS

General terms

Agent: *an organism associated with the epidemiology of OIE Lists A and B diseases.*

Animal import unit (AIU): *a live animal or a specified weight of product.*

Commodity: *an animal, animal product or animal by-product being considered for import.*

Risk: *a measure of the likelihood and magnitude of an adverse event (i.e. the entry, establishment and spread of a disease agent through the importation of a commodity).*

Risk analysis is an inclusive term for the following:

a) **Risk assessment**: *the process of identifying, estimating the statistical probabilities and evaluating the consequences of all risks associated with the importation of a commodity.*

b) **Risk communication**: *the process of relating the risk assessment results to the regulators of the import programmes, to industry and to the public.*

c) **Risk management**: *the decision-making process of identifying and implementing measures which can be applied to reduce the risk and document the final import decision.*

Transmission of infection

Direct transmission: *direct and essentially immediate transfer of an agent to a receptive portal of entry through which animal or human infection may take place* (68). This may occur by direct physical contact (e.g. trichomoniasis, rabies), contact with infected excretions and secretions (e.g. bovine brucellosis, leptospirosis) or contact with respiratory droplets (e.g. contagious bovine pleuropneumonia).

Indirect transmission can take place in a number of ways, as follows:

a) **vehicle-borne**: *transfer of an agent to a receptive portal of entry (particularly the gastrointestinal tract) via the contamination of bedding (e.g. foot and mouth disease), surgical instruments (e.g. iatrogenic transmission of anaplasmosis), feed (e.g. pork meat scraps fed to swine and transmitting hog cholera) or any material or objects by which the agent can be transported and introduced to a susceptible animal or human.* The agent may or may not have multiplied or developed in or on the vehicle (68, 79, 95).

b) **vector-borne** transmission is of three kinds:

– **mechanical**: *carriage of an agent on the exterior or in the proboscis of an arthropod, or by passage of the agent through the gastrointestinal tract of the arthropod.* Multiplication or development of the agent is not required (68, 95); an example of such transmission is equine infectious anaemia.

– **biological**: *a vector (arthropod) in which an agent undergoes either a necessary part of its life cycle or multiplication before transmission* (68, 95), *as occurs with babesiosis and theileriosis.*

c) **air-borne**: *transmission of particles, consisting wholly or partly of the agent, through the air and frequently over long distances.* The portal of entry is usually the respiratory tract (68, 95); for example, foot and mouth disease (23) and Aujeszky's disease in swine (88).

Hosts

Host: *a person, animal, bird or arthropod which is or can become infected with and give sustenance to an agent* (68, 102).

Primary (natural) host: *a person or animal which maintains an infection* (102); *for example, hog cholera in swine.*

Secondary host: *a species which is additionally involved in maintaining the infection but is not the principal source of infection* (102); *for example, Aujeszky's disease in cattle.*

Definitive host: *a term reserved for parasitic infections to describe a person or animal in which the agent undergoes sexual reproduction* (102); *for example,* Taenia saginata *infection of man.*

Intermediate host: *a term reserved for parasitic infections to describe a person or animal in which the agent develops only to a larval stage or asexual state* (102); *for example,* Cysticercus bovis *in cattle.*

Carrier: *a person or animal which harbours an agent and serves as a potential source of infection yet shows no clinical disease* (79). "Incubatory carrier" is the designation given to persons or animals during the incubation period of a disease, while "convalescent carrier" implies infection persisting during the recovery period. This carrier state may occur throughout the disease course following infection.

Latent infection: *a persisting infection within the host without clinical disease and often without demonstrable presence of the agent in blood, secretions or excretions* (68). There is a balance between the host and replication of the agent for what can be a considerably long time (102); for example, African swine fever virus and latent hog cholera infections in swine following recovery.

EVENTS AND THEIR PROBABILITIES

Following the importation of one animal import unit (AIU) – whether this consists of a live animal or a product equivalent – the following events or states of nature result in a disease outbreak event (O):

A – the AIU is infected with the agent

B – the agent survives commodity handling, treatment or in-transit time

C – the commodity is exposed to susceptible animals or man

D – the agent is exposed to a portal of entry and is transmissible via a mode of transmission

E – the agent induces infection (entry and development or multiplication of the agent)

F – the infection induces disease

G – disease spreads

H – disease is detected.

This is a generic set of events, which will differ according to the particular epidemiology of each disease. For example, anaplasmosis and babesiosis involve vectors, cysticercosis involves more than one scenario of exposure related to the definitive and intermediate hosts, and humans may be involved in the transmission of a disease agent from animal or product to animal. In addition, there are many factors involving the agent, susceptible host and environment. Agent factors include the infectivity of the strain of agent, the ability of the agent to produce disease (pathogenicity), the virulence or severity of the disease produced by the agent, the immunogenicity and antigenic stability of the agent, and the viability of the agent in the environment. However, for the present purpose, the list of events is an adequate generalization. On the basis of the available scientific evidence, the probabilities of the events occurring are determined as follows:

P(O) = probability that a disease outbreak occurs following the importation of one AIU of the commodity

$$= P(A) \times P(B|A) \times P(C|A \cap B) \times P(D|A \cap B \cap C) \times \ldots \times P(H|A \cap B \cap C \cap D \cap E \cap F \cap G).$$

In words, these probabilities are as follows:

P(A) = probability that the AIU is infected with the disease agent (i.e. the prevalence of the disease in the exporting country)

P(B|A) = conditional probability of the survivability of the agent, given that the AIU is infected

P(C|A∩B) = conditional probability of exposure of the commodity to susceptible animals or humans, given that the AIU is infected and the agent survives in the commodity

P(D|A∩B∩C) = conditional probability that the agent is transmissible via the mode of transmission, given that the AIU is infected, the agent survives in the commodity and the commodity is exposed to susceptible animals or humans

etc.

When the importation of a group of *n* AIUs is considered, P(O) is not obtained as a product of a prior and several conditional probabilities, but through a computation based on the binomial distribution. The assumption is made that infection within the importing country is possible if at least one of the AIUs is infected at the port of entry.

P(O) = P(at least one AIU is infected at port of entry and disease is detected)

$$= P(I \cap X) = P(I) \times P(X|I)$$

where:

P(I) = probability that at least one AIU is infected at the port of entry

P(X|I) = probability that exposure, transmission, infection, disease and disease detection occur, given that at least one AIU is infected at port of entry

$P(I) = 1 - P(\bar{I}) = 1 - P(\text{no AIUs are infected at port of entry})$.

The above events and their probabilities provide the basis for a risk assessment model.

QUANTITATIVE RISK ASSESSMENT MODEL

Unrestricted risk assessment

A simple mathematical model can estimate the probability of a disease risk associated with an importation. This model does not evaluate the magnitude or consequence component of risk and risk assessment. The unrestricted risk estimate (URE) gives the risk associated with the importation of a commodity in the usual commercial form. The word "unrestricted" represents the risk before selecting and applying any risk reduction options, such as diagnostic testing, quarantine and further processing. The URE consists of the product of two probabilities, the probability of agent entry (PAE) and the probability of domestic exposure (PDE).

$$URE = (PAE) \times (PDE) \qquad \text{(expression 1).}$$

A risk reduction option reduces either the PAE or the PDE, depending on the point of application. This risk management tool results in the computation of a restricted risk estimate and, depending on the measure, this can dramatically reduce the risk estimate.

Probability of agent entry

The PAE is the probability that at least one AIU of the commodity importation is infected.

In expression 2 below, CF1 represents the country factor, CF2 the commodity factor and *n* AIUs the number of animal import units:

$$PAE = 1 - (1 - CF1 \times CF2)^{\text{n AIUs}} \qquad \text{(expression 2).}$$

The part of the expression within parentheses (with the exponent *n* AIUs) represents the probability that no animal import units are infected.

The PAE for a specified number of animal import units of a particular commodity is identical for all importing countries, while the PDE incorporates the events and their probabilities which exist in the importing country. In all importing countries, these events of exposure and (most certainly) the associated probabilities are different.

Country factor

In the quantitative risk assessment of animal commodity importation, the presence and level of disease in the exporting country are key elements. For very large importations, knowledge of the prevalence of infection in the population of animals of the species concerned is essential. However, for importations of small quantities, knowledge of the prevalence in a single herd, a group of herds, or animals reared using

a particular type of husbandry or in a particular region may be more appropriate. Obviously, the country-wide prevalence of a disease may be quite different to the prevalence in herds, groups of herds or regions. However, the OIE disease reporting system is based on country reporting. Importing countries assess the risks associated with an importation based on the disease status of the entire exporting country.

In this paper, examples of the importation of cattle, swine and related products portray the quantitative risk assessment model. The Appendix to this paper represents the Animal Health Statistics and Disease Control Methods table of the OIE publication *World Animal Health in 1992* for a fictional country called "Country A", indicating the 1992 animal populations and number of herds and disease statistics for diseases affecting cattle and swine in the country. These data illustrate the numerical computations.

List A diseases (excluding bluetongue)

Calculated prevalence can be determined as a product of the number of outbreaks in the previous 12 months, the average herd size (AHS) and the average duration of infection (ADI) over the denominator of the number of animals in the population:

$$\text{Calculated prevalence} = \frac{(\text{No. of outbreaks} \times \text{AHS} \times \text{ADI})}{\text{Population}} \qquad \text{(expression 3).}$$

An outbreak is defined as the occurrence of infection (disease) within a herd; this is less inclusive than the OIE *International Animal Health Code* definition. The AHS is estimated by dividing the livestock population by the number of herds; these data are reported annually to the OIE. In this example, Country A has an AHS of 271 cattle and 371 swine.

The ADI can be estimated with the epidemiological parameters of the disease in cattle and swine as presented in Table I. The computation of the ADI is based on the following:

a) the maximum and minimum duration of the incubation period (IP)

b) the maximum and minimum duration of the disease course (DC) over all forms

c) the maximum and minimum case fatality rate (CFR)

d) the proportion of surviving animals which become latently infected (LIS)

e) the maximum duration of latent infection (latent period: LP).

The uniform distribution is used to represent each of these variables (83). The two distributions of incubation period and disease course are aggregated and integrated with the case fatality and latent infection distributions using the Latin Hypercube simulation of a computer software programme (@Risk, Palisade Corporation, Newfield, New York, United States of America). Where only point estimates are available, these are employed.

The computation may be expressed as follows:

$$(\text{IP}+\text{DC}) \times (\text{CFR}) + (\text{IP}+\text{DC}) \times (1-\text{CFR}) \times (1-\text{LIS}) + (\text{LP}) \times (\text{LIS}).$$

For hog cholera, the number of days post-infection includes the incubation period and the disease course.

TABLE I

Average duration of infection estimated by the epidemiological parameters of nine Office International des Epizooties List A diseases in cattle and swine

Parameter	Foot and mouth disease		Vesicular stomatitis		Swine vesicular disease	Rinderpest	Contagious bovine pleuro-pneumonia	Lumpy skin disease	Rift Valley fever	African swine fever	Hog cholera
Species affected	Cattle	Swine	Cattle	Swine	Swine	Cattle	Cattle	Cattle	Cattle	Swine	Swine
Incubation period (days)	1-7	2-8	1-2	1-3	2-14	3-9	21-42	14-28	0.5-1	5-15	2-6
Case fatality rate (%)	2-20	2-20	0	0	0	30-90	50	1-5	5-10	5-100	95-100
Disease duration											
- Peracute form (days)											5 (PI)
- Acute form (days)	4-11	7	3-4	14	14-21	1-2	7-21	35	1-2	5-10	10-20 (PI)
- Subacute form (days)						12-21				21-28	20-29 (PI)
- Chronic form (days)											30 (PI)
Duration of latent infection (days)	180	30	0	0	0	0	180-1,095	0	0	180-730	30-120
Survivors latently infected (%)	50	100	0	0	0	0	25	0	0	100	100
Average duration of infection (days)	86	28	5	16	26	17	120	56	3	230	19
References	(23, 78)	(23)	(23, 56)	(23, 31)	(23, 60)	(23, 94)	(21, 23, 51, 91)	(23, 71, 111)	(23, 71, 110)	(23, 71, 108)	(23, 42, 106)

PI = post-infection

In some countries where the disease is enzootic, mortality may be very low and the proportion of latently infected animals may be very high. This is in contrast to epizootic situations where the reverse may occur (i.e. high mortality and low level of latent infection).

The ADI for contagious bovine pleuropneumonia is 120 days (0.33 years) (Table I). The reporting of 10 outbreaks of contagious bovine pleuropneumonia during 1992 by Country A (Appendix) gives a calculated prevalence of $(10 \times 271 \times 0.33)/23,212,325 = 3.9 \times 10^{-5}$. Similarly, for hog cholera, the 86 reported outbreaks and the ADI of hog cholera of 19 days (0.05 years) gives a calculated prevalence of $(86 \times 371 \times 0.05)/26,850,250 = 5.9 \times 10^{-5}$.

Obviously, the AHS is a crude statistic based on country-wide estimates of the population of animals and herds for a species. Despite this, the computation of the prevalence based on the number of outbreaks – rather than the reported number of cases – provides a greater level of security for the importing country. Here, a herd outbreak implies that all animals within an outbreak herd are diseased. This security may justify the use of the crude AHS statistic.

List B diseases and bluetongue

A number of these diseases are notifiable in Member Countries of the OIE. Some countries report the number of outbreaks and the number of cases and disease control statistics for these notifiable diseases. However, for the majority of diseases, only a nominal measure of disease prevalence is indicated.

Under the "Occurrence" column of the Animal Health Statistics and Disease Control Methods table of the OIE publication *World Animal Health*, an indication of either incidence or prevalence is given, depending on the disease. The incidence of rabies cases, bovine spongiform encephalopathy (BSE) cases, anthrax outbreaks or cases, and screwworm outbreaks are often used to subjectively assign a level of disease occurrence. In the same column, knowledge of the serological or abattoir prevalence of other diseases is used to indicate the level of disease occurrence. In order to assess these disease risks, a single numerical measure of disease occurrence is necessary, i.e. prevalence of infection. This permits consistency in the reporting of disease occurrence and the reporting of the levels of infection, and also gives a measure of the level of infection of these diseases on a comparable basis.

The natural history of a disease is influenced by control and eradication programmes instated by the rearer of the animals and by national and sub-national governments. The levels of disease obtained within a herd, region or country are thus often less than would exist if the disease were allowed to spread naturally. In each country, the conditions of control, management, husbandry and environment influence the prevalence of the disease. Using the scientific literature to illustrate the dynamics of the interaction between the disease and control, one can obtain a numerical range of prevalence. This can then be correlated with the reported disease occurrence levels: exceptional, low sporadic, enzootic and high.

The three other disease occurrence designations can be assigned to the "exceptional" level of prevalence. These are as follows:

- suspected but not confirmed
- serological evidence and/or isolation of causative agent; no clinical disease
- disease exists; distribution and occurrence unknown.

Depending on an evaluation of the Veterinary Services, an importing country may desire to assign a higher level to these less descriptive designations.

The most expeditious and comprehensive source of prevalence information is the publication *Animal Disease Occurrence*. This is an annual annotated bibliography of the Centre for Agriculture and Biosciences International (CABI) Information Services. For this paper, the most recent six years of this publication, 1986-1991 (28), provided a current and thorough indication of the range of disease prevalence on a global basis.

The criteria for selecting abstracts are as follows:

a) Select abstracts (country disease reports, slaughter statistics, and reports of surveys and serological investigations in endemic areas and of control and eradication programmes) where prevalence and the number of animals tested or examined are indicated.

b) Omit studies involving the investigation of disease levels in animals or herds exhibiting or suspected of disease, and in specific breed or husbandry groups.

c) Select only the most recent annual disease reports in any country.

d) Omit any abstracts in which the prevalence is not clearly indicated or where the numbers of animals tested or examined is less than 100. With respect to the latter criterion, for some countries where the animal population is small or the abstract is considered useful because of its geographic origin, these abstracts are used.

e) Select abstracts limited to one or two diagnostic methods for any one disease. For example, for anaplasmosis, babesiosis and enzootic bovine leukosis, only abstracts reporting serological findings (seroprevalence) are used, rather than both serological and blood smear survey statistics.

The range of prevalence observed globally is used to indicate the exceptional and the high level of disease prevalence. Points between these two values (quartiles) are correlated to low sporadic and enzootic. Seroprevalence, slaughter prevalence, and prevalence of parasitaemia, lesions and disease represent surrogate measures of prevalence of infection. The extent to which these measures approximate the prevalence of infection in the animal population of a country varies with the disease, the measurement tool and the subset of the population which is surveyed. With some diseases, the level varies considerably with the time of year, related to the climate (specifically the vector season) and husbandry.

The seroprevalence of anaplasmosis, babesiosis, brucellosis and enzootic bovine leukosis may provide a good measure of the true level of infection in cattle over six months of age, whereas the seroprevalence of bluetongue (48) and infectious bovine rhinotracheitis (101) may overestimate the prevalence of infection to a considerable degree. These measures are usually obtained on a definite subset of the population, such as breeding animals, slaughter animals or culled breeding stock. Despite these deficiencies, the surrogate measurements give the best available indication of the true infection level.

With abstracts which report more than one prevalence – usually because of surveys of multiple regions in a country – the highest prevalence value is recorded. Table II presents this correlation of disease occurrence and prevalence levels.

TABLE II

Upper prevalence levels for each nominal level of disease occurrence of the Office International des Epizooties (OIE) List B diseases of cattle and swine

Disease	Species	OIE disease occurrence designations			
		Exceptional	Low sporadic	Enzootic	High
Bluetongue [a]	Cattle	9×10^{-3} *	2×10^{-1}	7×10^{-1}	9×10^{-1}
Anthrax [b]	Cattle	1×10^{-9}	1×10^{-6}	3×10^{-6}	4×10^{-6}
	Swine	ND	ND	ND	ND
Aujeszky's disease [a]	Cattle	ND	ND	ND	ND
	Swine	2×10^{-4}	2×10^{-1}	5×10^{-1}	6×10^{-1}
Echinococcosis/ hydatidosis [c]	Bovine	1×10^{-4}	8×10^{-2}	2×10^{-1}	3×10^{-1}
	Swine	1×10^{-4}	1×10^{-1}	4×10^{-1}	6×10^{-1}
Heartwater [b]	Cattle	3×10^{-8}	1×10^{-5}	4×10^{-5}	5×10^{-5}
Leptospirosis [a]	Bovine	4×10^{-3}	2×10^{-1}	6×10^{-1}	8×10^{-1}
	Swine	3×10^{-3}	2×10^{-1}	5×10^{-1}	6×10^{-1}
Rabies [b]	Cattle	2×10^{-8}	7×10^{-6}	2×10^{-5}	3×10^{-5}
	Swine	ND	ND	ND	ND
Paratuberculosis [a, d]	Bovine	8×10^{-3}	2×10^{-1}	6×10^{-1}	8×10^{-1}
Screwworm [b]	Cattle	ND	ND	ND	ND
Q fever [a]	Bovine	3×10^{-2}	1×10^{-1}	3×10^{-1}	4×10^{-1}
Anaplasmosis [a]	Bovine	5×10^{-3}	2×10^{-1}	7×10^{-1}	9×10^{-1}
Babesiosis [a]	Bovine	1×10^{-2}	2×10^{-1}	7×10^{-1}	9×10^{-1}
Bovine brucellosis (*Brucella abortus*) [a]	Bovine	1×10^{-5}	1×10^{-1}	4×10^{-1}	5×10^{-1}
Bovine genital campylobacteriosis [d]	Bovine	9×10^{-2}	1×10^{-1}	2×10^{-1}	3×10^{-1}
Bovine tuberculosis (*Mycobacterium bovis*) [e]	Bovine	1×10^{-5}	7×10^{-2}	2×10^{-1}	3×10^{-1}
Cysticercosis (*Cysticercus bovis*) [c]	Bovine	2×10^{-5}	1×10^{-1}	3×10^{-1}	4×10^{-1}
Dermatophilosis [d]	Bovine	3×10^{-2}	2×10^{-1}	4×10^{-1}	6×10^{-1}
Enzootic bovine leukosis [a]	Bovine	2×10^{-4}	1×10^{-1}	3×10^{-1}	4×10^{-1}
Haemorrhagic septicaemia [b]	Cattle	2×10^{-8}	8×10^{-5}	2×10^{-4}	3×10^{-4}
Infectious bovine rhinotracheitis [a]	Bovine	2×10^{-2}	2×10^{-1}	5×10^{-1}	7×10^{-1}
Theileriosis [a, d]	Bovine	2×10^{-1}	4×10^{-1}	7×10^{-1}	9×10^{-1}
Trichomoniasis [d]	Cattle	ND	ND	ND	ND
Trypanosomiasis [a, d]	Bovine	6×10^{-2}	2×10^{-1}	5×10^{-1}	7×10^{-1}

TABLE II (contd)

Disease	Species	OIE disease occurrence designations			
		Exceptional	Low sporadic	Enzootic	High
Bovine malignant catarrh [b]	Cattle	ND	ND	ND	ND
Bovine spongiform encephalopathy [b]	Cattle	ND	ND	ND	ND
Atrophic rhinitis [c]	Swine	1×10^{-2}	2×10^{-1}	6×10^{-1}	8×10^{-1}
Cysticercosis (*C. cellulosae*) [c]	Swine	9×10^{-7}	5×10^{-2}	2×10^{-1}	2×10^{-1}
Porcine brucellosis (*B. suis*) [a]	Swine	4×10^{-4}	6×10^{-2}	2×10^{-1}	2×10^{-1}
Transmissible gastroenteritis of pigs [a]	Swine	1×10^{-2}	9×10^{-2}	3×10^{-1}	3×10^{-1}
Trichinellosis [a, c]	Swine	3×10^{-8}	1×10^{-2}	4×10^{-2}	5×10^{-2}

* figures are rounded to a single digit
ND: insufficient or no data

a) seroprevalence
b) disease prevalence based on incidents
c) slaughter prevalence
d) prevalence of lesions, parasitaemia, isolation of organism
e) tuberculin test reactor rate

Multiple agents exist for protozoal and rickettsial diseases of cattle, and concurrent infections can exist (as occurs with multiple serovar leptospirosis infections). Prevalence figures for these diseases therefore refer to prevalence of infection with one or more agents. The causative agents associated with each of these diseases and for which disease prevalence information is pertinent are as follows:

Trypanosomiasis:	*Trypanosoma brucei* *T. congolense* *T. vivax* (71, 99)
Theileriosis:	*Theileria parva* *T. lawrenci* *T. annulata* *T. mutans* (47, 71)
Babesiosis:	*Babesia bigemina* *B. bovis* *B. divergens* *B. major* (23, 71)
Anaplasmosis:	*Anaplasma marginale* *A. centrale* (23, 71).

Insufficient data were available for estimation of the prevalence for rabies in swine, Aujeszky's disease, screwworm, trichomoniasis, bovine malignant catarrh and BSE in cattle. Only a few countries reported cases of BSE during 1991. Based on the section of the cattle population over two years of age, annual incidences of between 3.0×10^{-7} and 3.2×10^{-3} were observed (the upper value represents a 1990 incidence) (5). Bovine

malignant catarrh is sporadic in occurrence, recurring at intervals over many years (89). This may explain the paucity of reported outbreaks for this disease. Rabies in pigs is rare (8) and Aujeszky's disease in cattle is only seen where cohabitation with swine exists. There is no evidence of inter-bovine transmission of Aujeszky's disease (82).

Screwworm myiasis caused by *Cochliomyia hominivorax* occurs in the tropical and semitropical regions of the Americas (34), but few reports of outbreaks or surveys exist in the current literature.

Trichomoniasis of cattle caused by *Tritrichomonas foetus* is now a rarity in many countries, probably due to the use of artificial insemination (86). Only a few reports exist in the literature, relating to surveys of bulls.

For anthrax, heartwater, rabies and haemorrhagic septicaemia, the minimum and maximum prevalence are estimated from the annual incidence (cases or deaths) reported by OIE Member Countries. This parameter and the ADI are used to compute the minimum and maximum prevalence (Table III). Intermediate values are computed as with the other disease entities. Few reports of these diseases exist in the literature.

TABLE III

Average duration of infection and maximum and minimum incidence of four Office International des Epizooties List B diseases for which prevalence estimation is based on the reported number of cases/deaths

Parameter	Anthrax [a]	Heartwater [a]	Rabies [b]	Haemorrhagic septicaemia [a, c]
Species	Cattle	Cattle	Cattle	Cattle
Incubation period (days)	7-14	7-21	35-75	2-3
Mortality (%)	100	50-100	100	90-100
Duration				
- Peracute form (days)	0.04-0.08	1	-	1-2
- Acute form (days)	1-2	6	6-7	2-5
- Subacute form (days)	-	-	-	-
- Chronic form (days)	-	-	-	-
Duration of latent infection (days)	0	0	0	40-240
Survivors latently infected (%)	0	0	0	100
Average duration of infection (days)	12	18	62	12
Reported number of cases/deaths (1991)				
- Minimum incidence	4.7×10^{-8}	5.2×10^{-7}	1.1×10^{-7}	5.8×10^{-7}
- Maximum incidence	1.4×10^{-4}	9.4×10^{-4}	1.6×10^{-4}	1.0×10^{-2}
References	(23)	(30)	(9)	(46)

a) incidence computed from the annual number of cases and the total cattle population reported for 1991
b) incidence computed from the annual number of deaths and the total cattle population reported for 1991
c) haemorrhagic septicaemia in buffalo was classified as cases in cattle; this overestimates the prevalence in cattle as, in some countries, the majority of cases and deaths occur in buffalo (46)

Commodity factor

The commodity factor (CF2) is an estimate of the probability of the agent being present at the time of import.

Younger animals are less likely to be infected with most diseases. Certain breeds of animals are less susceptible to infection, such as the Ile de France breed of sheep which exhibit less susceptibility to maedi-visna infection (65). These determinants (age and breed) have a definite impact on the level of risk associated with an importation. The importation of young animals almost always produces lower risk than with animals from the general population.

Concerning the importation of meat, meat products, milk and milk products – which represent the vast majority of the trade in products of cattle and swine – other determinants exist. These are related to the epidemiology of the disease, the agent, the product properties and the processing involved in preparation of the product. Transmission and agent survival studies indicate the presence or absence of agents in various products, and the CF2 and its component determinants are deduced from the reported findings.

The OIE Lists A and B diseases of cattle and swine which are generally of concern with product importation are foot and mouth disease, swine vesicular disease, hog cholera, African swine fever, anthrax, echinococcosis, bovine brucellosis, bovine tuberculosis, Q fever, bovine spongiform encephalopathy, cysticercosis, enzootic bovine leukosis, transmissible gastroenteritis and trichinellosis.

Sources of information

The following represents sources of information which are useful for determining the CF2 associated with the importation of meat and milk and related products.

Meat and meat products

Reviews

- foreign animal disease agent survival in animal products (13)
- viruses in products of food animals (14, 18)
- meat and meat product importation (72).

Foot and mouth disease

Reviews

- persistence of foot and mouth disease virus (FMDV) in animals, animal products and the environment (36).

Epidemiology

- persistence of FMDV in beef and pork (93)
- presence and persistence of FMDV in bovine skin (53)
- sites of virus persistence and multiplication in the carrier animal (24)
- sites of pre-viraemic localization and multiplication (27).

Products and processing

- survival of FMDV in fresh and stored beef carcass meat (37, 38)
- inactivation of FMDV by pH and temperature changes (7)
- FMDV and meat processing (92)
- thermal processing at 69°C (75)
- international trade from FMD-infected countries (22)
- electrical stimulation on pH and survival of FMDV in meat and offals (3)

- Parma ham (77)
- ingredient effects on the thermal inactivation of FMDV in formulated, comminuted meat products (20)
- total caloric input of a thermal process for ground beef (19)
- Italian salami (84)
- effects of heat, irradiation and pH on infectivity (69)
- persistence of FMDV on meat-packaging materials (54)
- persistence of FMDV in meat products (93)
- effects of heat, freezing/thawing, salt/citric acid curing and curing salts on FMDV infectivity (61).

Hog cholera

Epidemiology

- transmission and pathogenesis (42, 58, 106).

Products and processing

- cooked and uncooked smoked ham and sausage casings (62)
- thermal processing at 69°C (75)
- brined hams (74)
- cooked canned hams (74, 100)
- dried salami and pepperoni sausages (74)
- ham muscle, fat and bone marrow (93)
- Parma ham (77)
- Italian salami (85)
- tissue distribution of agent (109).

African swine fever

Epidemiology

- transmission and pathogenesis (108).

Products and processing

- dried salami and pepperoni sausages, brined hams, heated hams (74)
- Parma ham (77)
- thermal processing at 69°C (75).

Swine vesicular disease

Epidemiology

- pathogenesis (60).

Products and processing

- survival of the agent in carcass meat (44)
- dry salami, pepperoni sausage, intestinal casings, cooked canned hams (13, 73, 74)
- Parma ham (76)
- survival of the agent in organs, tissues, sausages, salami and mortadella (52)
- thermal processing at 69°C (75).

Anthrax

Epidemiology

- pathogenesis (23)

- survival of organisms and spores in the environment, meat, milk, hair, wool and hides (81).

Products and processing

- bone meal (43).

***Echinococcosis* (Echinococcus granulosus)**

Epidemiology

- transmission and source of infection (1).

***Cysticercosis* (Cysticercus bovis *and* C. cellulosae)**

Epidemiology

- zoonotic cycle (6, 64, 96)
- human health and livestock production (49).

Bovine spongiform encephalopathy

Epidemiology

- transmission, tissue distribution (4, 5, 67).

Products and processing

- restrictions on trade and use of meat-and-bone meal (67)
- non-detectable infectivity in carcass meat (5).

Trichinellosis

Epidemiology

- zoonotic cycle (1, 97).

Products and processing

- inactivation of the trichinellosis parasite (103).

Transmissible gastroenteritis

Epidemiology

- distribution of virus (57)
- persistence of virus in lung and small intestine (104)
- oral transmission using carcass meat of acutely-infected swine (35, 50).

Milk and milk products

Reviews

- foreign animal disease agent survival in animal products (13)
- viruses in products of food animals (14).

Foot and mouth disease

Reviews (29, 36, 63)

Epidemiology

- the role of milk in the transmission of FMDV during outbreaks (45)
- FMDV replication in the mammary glands (16, 17, 26, 66)
- the presence of FMDV in the milk of incubatory carrier animals (25, 59)

- non-detection of FMDV in the milk of cows previously vaccinated after intranasal challenge with FMDV (70).

Products and processing

- survival of FMDV in cheese (10)
- inactivation of FMDV in ultra-high temperature processed milk (41)
- effect of pasteurization and evaporation on FMDV in whole milk (66)
- effect of heat on FMDV in skimmed milk, cream and pelleted cellular debris (15)
- heat treatment of FMDV-infected milk (107)
- persistence of FMDV in butter and butter oil (11)
- FMDV in whey constituents (12)
- persistence of FMDV in dried casein (40)
- survival of FMDV in casein and sodium caseinate (39).

Q fever

Epidemiology

- transmission and source of infection (1).

Products and processing

- high-temperature, short-time milk pasteurization (2).

Bovine brucellosis

Epidemiology

- transmission and pathogenesis (1, 23).

Products and processing

- survival of *Brucella abortus* in butter, cream, milk and milk products (81).

Bovine tuberculosis

Epidemiology

- transmission and pathogenesis (1, 23).

Products and processing

- survival of *Mycobacterium bovis* in milk and milk products (81).

Enzootic bovine leukosis

Epidemiology

- transmission and pathogenesis (105).

Products and processing

- pasteurization (33).

Bovine spongiform encephalopathy

Epidemiology

- transmission, tissue distribution (4, 5, 67).

Products and processing

- non-detectable infectivity in milk (5).

Animal import units

The number of units imported significantly influences the PAE. As the number of AIUs is the exponent of expression 2, this has the most significant effect on the PAE. As the importation increases in quantity, it is obvious that the chance of disease risk increases.

A single animal of any species represents one AIU for the species. An embryo or a unit of semen can be considered as one AIU. Meat, meat products and other products of animal origin are given a weight equivalency (in kg) for one AIU. The number of AIUs represents the expected number of animals which have contributed to the total weight of the importation.

The yield in kg of carcass organs, carcass portions, glands, hides and by-products varies considerably. Breed, sex, age, live weight at slaughter and the amount of trimming of fatty tissue and skin all influence the weights of carcass and offal. The difference in weight between fresh or frozen and preserved products is often substantial. For instance, salt curing of cattle hides gives a net decrease of approximately 15-20%, primarily due to water loss (90). The trimming and preparation of carcass portions gives a wide variation in the weight of the fresh or frozen product. A pork ham may exist in four forms (87):

- untrimmed (with only the foot removed)
- regular (with the tail-bone, flank and foot removed)
- skinned (with the foot, tail-bone, flank and half of the skin removed)
- skinless (as for skinned ham, except that all the skin is removed).

Tables IV to VIII illustrate some of the variability encountered with organs, hides and carcass portions of cattle and swine. In Table VIII, the carcass portions of swine are representative of an 80 kg carcass and hence a wider range of portion weights will be seen with the range of carcass weights encountered at slaughter. In estimating the number of animals which have contributed to a certain weight of product, the product must be fully described with regard to the average individual weight or the range of weights for the individual product. This more accurately estimates the animal contribution than using the fresh weights.

TABLE IV

Expected weight range of organs of cattle and swine (98)

Animal type	Live weight (kg)	Organ weight (kg)				
		Brain	Heart	Kidney	Liver	Tongue
Swine	43-60	-	0.13-0.18	0.12-0.21	0.68-0.96	0.11-0.16
Swine	60-75	-	0.18-0.25	0.13-0.22	1.15-1.66	0.15-0.21
Yearling cattle	200-300	0.23-0.26	1.28-1.47	0.64-0.94	2.70-4.80	1.50-1.75
Steers (bullocks)	300-500	0.28-0.35	1.20-2.00	0.60-1.20	3.50-6.20	1.40-1.88
Cows	300-400	0.24-0.28	-	0.58-0.78	3.00-4.60	1.38-1.49
Cows	450-600	-	1.80-2.40	1.00-1.60	4.00-8.60	-
Bulls	450-550	0.32-0.36	1.89-2.06	0.80-1.20	5.18-6.40	1.57-1.94

TABLE V

Expected weight range of fresh cattle hides
(90)

Animal type	Hide weight (kg)
Calf	<4.1 - 24.1
Cow	>24.1
Steer (bullock)	<21.8 - >26.4
Bull	27.3 - >45.5

TABLE VI

Estimated average yield of meat meal and dried blood for animal feeds (in kg per 10,000 kg of live weight)
(90)

Animal type	Meat meal (meat and bone meal, tankage)	Dried blood
Cattle	27	7
Calves	15	3
Hogs	10	5

TABLE VII

Estimated average yield of glands of cattle and swine for pharmaceuticals
(55)

Gland	No. of animals required to produce 500 g of fresh material	No. of glands required to produce 500 g of finished product
Pituitary (whole, cattle)	199	1,100
Ovary (cow)	39	210
Ovary (sow)	50	298
Parathyroid (cattle)	243	1,990
Suprarenal (cattle)	22	127
Pancreas (cattle)	2	26,500
Pancreas (calf)	18	8,830
Pancreas (pig)	11	132,500
Testis (bull)	1.5	7
Thyroid (cattle)	22	100,110

TABLE VIII

Expected weight range of fresh/frozen pork portions of an 80 kg carcass
(87)

Type of portions	Weight range (kg)
Regular hams (22-28% of carcass)	17.6-22.4
Skinned ham (17-19% of carcass) (foot, tail bone, flank and half of the skin having been removed)	13.6-15.2
Shoulder (23% of carcass)	18.4
Trimmed shoulder (14-16% of carcass) (neck bones, ribs, breast flap and foot having been removed and one-third collar of skin left on the picnic)	11.2-12.8
Picnics (lower half of the skinned pork shoulder, the ribs, neckbones and breast flap having been removed and the foot cut off at the knee joint or one inch above)	3.6->7.3
Boston butts (upper halves of pork shoulders)	3.6->7.3
Boneless boston butts	1.4->5.5
Trimmed bellies (14% of carcass) (ribs having been removed, skin on)	11.2
Untrimmed loins (20% of carcass)	16
Trimmed loins (14-17% of carcass)	11.2-13.6

The individual portion weight of carcass halves and carcass portions can usually be considered as twice the weight in kg for a single animal contribution. If the average weight of a pork ham product is 10 kg, the contribution per animal is 20 kg (two hams), representing one AIU. If the range in weights for this product is 6.4-13.6 kg, one could use the lower value; 12.8 kg would therefore represent one AIU. The latter method overestimates the number of AIUs contributing to the overall weight of the importation.

Probability of agent entry computed

Table IX indicates the PAE for four commodities being imported from Country A. The CF2 is essentially zero for all commodity/disease combinations where values are not indicated. The computation of the PAE is based on expression 2 above. A PAE of 1.00 indicates that there is 100% probability that at least one AIU is infected at the port of entry. Tables Xa and Xb expand the computations for two disease risks associated with the importation of a boneless ham product and the importation of breeding cattle.

For the importation of live cattle, the CF2 is considered to be 1.00. This is equivalent to saying that the age group from which the importation originates has no influence on the population prevalence. However, with the importation of beef half-carcasses and livers, the CF2 for some of the disease risks is negligible, and zero values can be employed. This is due to the pathogenesis and predilection sites of the agent, as observed with contagious bovine pleuropneumonia (91), paratuberculosis (32) and bovine genital campylobacteriosis (23, 86). With respect to the rabies agent in carcass meat importation, the virus is assumed to be potentially present, although it has never been isolated from meat (9). The CF2 for rabies virus in liver importation is assumed to have zero value.

TABLE IX

Probability of agent entry of four commodities from Country A

Disease/agent	1,000 breeding cattle	20,000,000 kg half-carcasses of beef	20,000,000 kg carcasses of pork	100,000 kg frozen cattle livers
	1,000 AIU	80,000 AIU[a]	400,000 AIU[b]	20,000 AIU[c]
Contagious bovine pleuropneumonia	4×10^{-2}	–	–	–
Hog cholera	–	–	1.00	–
Anthrax	1×10^{-6}	8×10^{-5}	–	2×10^{-5}
Aujeszky's disease	–	–	1.00	–
Echinococcosis	1×10^{-2}	1.00	1.00	1.00
Leptospirosis	1.00	–	–	–
Q fever	1.00	1.00	–	1.00
Rabies	2×10^{-5}	2×10^{-3}	–	–
Paratuberculosis	1.00	–	–	–
Anaplasmosis	1.00	1.00	–	1.00
Bovine brucellosis	1×10^{-2}	1.00	–	1.00
Bovine genital campylobacteriosis	1.00	–	–	–
Bovine tuberculosis	1×10^{-2}	1.00	–	1.00
Cysticercosis (*Cysticercus bovis*)	2×10^{-2}	1.00	–	1.00
Enzootic bovine leukosis	1.00	1.00	–	1.00
Infectious bovine rhinotracheitis	1.00	1.00	–	1.00
Atrophic rhinitis	–	–	–	–
Transmissible gastroenteritis	–	–	1.00	–
Trichinellosis	–	–	1.00	–

a) 250 kg = 1 AIU
b) 50 kg = 1 AIU
c) 5 kg = 1 AIU

AIU: animal import unit

The pathogenesis and mode of transmission of atrophic rhinitis (associated with toxigenic strains of *Pasteurella multocida*) preclude pork as a source of infection (23).

With respect to the products of cattle and swine, it is understood that there is a time delay – due to processing, packaging, storage, shipping and distribution – before the target species are exposed in the importing country. This means that some diseases which can be transmitted directly by contact with infected excretions and secretions do not present a risk, because the fragility and survival time of the agent in the product is limited. This is the case with leptospirosis agents (81) and rabies virus (9).

TABLE Xa

Probability of disease agent entry associated with the importation of 500,000 kg of 400-day-aged boneless pork ham weighing 7-9 kg, prepared according to the Parma ham process

Disease risk	Factors
Hog cholera (HC)	**Country factor** (86 outbreaks during 1991 × 371 average herd size × 0.05 average duration of infection in years)/26,850,250 swine population = 5.9×10^{-5} **Commodity factor** HC virus inactivated in less than the 400-day aging process (77); consider a very low value, e.g. 1×10^{-8} **Number of animal import units (n AIUs)** 500,000 kg/7 kg minimum weight per ham × 2 hams per pig = 35,714 AIUs **Probability of agent entry** $1-(1-\text{country factor} \times \text{commodity factor})^{n \text{ AIUs}}$ $= 1-(1-[5.9 \times 10^{-5} \times 1 \times 10^{-8}])^{35,714} = 2.1 \times 10^{-8}$ (probability that at least one animal import unit of the importation is infected) Of course, this very low risk on such a large annual importation applies only to this specific product. High levels of HC virus have been found in carcass muscle following intranasal inoculation (109). The viability of HC virus for other ham products depends on the processing and hence the commodity factor is based on the inactivation of the HC virus through the usual processing of the product (13, 62, 74, 100). Thermal inactivation of HC virus occurs after 15 min at 69°C (58)
Trichinellosis	**Country factor** Exceptional level of occurrence correlated to a prevalence from Table II $= 3.0 \times 10^{-8}$ **Commodity factor** Consider usual processing as not a determinant influencing survival of the parasite in the importation (103) = 1.0 **Number of animal import units (n AIUs)** = 35,714 AIUs **Probability of agent entry** $1-(1-\text{country factor} \times \text{commodity factor})^{n \text{ AIUs}}$ $= 1-(1-[3.0 \times 10^{-8} \times 1.0])^{35,714}$ $= 1.1 \times 10^{-3}$ (probability that at least one AIU of the importation is infected)

Probability of domestic exposure

The PDE represents the likelihood that the commodity is exposed to animals or humans in the importing country and that agent transmission, infection, disease, disease spread and disease detection occur. The scenarios for the exposure of a particular commodity to animals and humans – and simultaneously the exposure of the agent to a portal of entry for one or more species which are hosts of the disease – can be numerous. The modes of transmission of the disease dictate the exposure possibilities with different commodities.

TABLE Xb

Probability of disease agent entry associated with the importation of 1,000 male and female breeding Holstein dairy cattle 16-24 months of age

Disease risk	Factors
Contagious bovine pleuropneumonia	**Country factor** (10 outbreaks during 1991 × 271 average herd size × 0.33 average duration of infection in years)/23,212,325 cattle population = 3.9×10^{-5} **Commodity factor** Consider age and breed of cattle as not influencing level of disease in the importation = 1.0 (representing apparently healthy incubatory carrier animals) (91) **Number of animal import units (*n* AIUs)** 1,000 AIU **Probability of agent entry** 1 – (1 – country factor × commodity factor)$^{n\ AIUs}$ = $1 - (1-[3.9 \times 10^{-5} \times 1.0])^{1,000}$ = 6.0×10^{-2} (probability that at least one animal import unit of the importation is infected)
Bovine brucellosis	**Country factor** Exceptional level of occurrence correlated to the prevalence from Table II = 1.0×10^{-5} **Commodity factor** Consider age and breed of cattle as not influencing level of disease in the importation = 1.0 **Number of animal import units (*n* AIUs)** 1,000 AIU **Probability of agent entry** 1 – (1– country factor × commodity factor)$^{n\ AIUs}$ = $1 - (1-[1.0 \times 10^{-5} \times 1.0])^{1,000}$ = 1.0×10^{-2} (probability that at least one AIU of the importation is infected)

With the importation of animals, the PDE is considered absolute, and a value of 1.00 is used. The fact that certain animals are destined for zoos, laboratory facilities, urban areas and destinations remote from other animal populations has to be considered.

The importation of milk, milk products, meat, meat products and other products of cattle and swine involves the potential importation of disease agents. However, the modes of disease transmission dictate the possibility (probability) of transmission within the importing country. Table XI shows the OIE Lists A and B diseases which can be transmitted through the importation of cattle and swine and some related products. Vehicle-borne transmission occurs only if a susceptible target species consumes an infectious dose or a viable parasite in the infected commodity. Man is the most common target species, as many of the products are imported for human consumption. The discarding of meat scraps to swine for consumption places swine prominently as a target species.

TABLE XI

Some import commodity groups and associated modes of disease transmission and target species for the Office International des Epizooties Lists A and B diseases affecting cattle and swine

Commodity group	Scenario	Target host	Mode of entry	Mode of transmission facilitated	Potential diseases transmitted
Cattle	Contact	Domestic animals, man	Various	Direct, vector-borne	All Lists A and B diseases affecting cattle
Bovine semen	Contact	Cattle	Reproductive	Direct	FMD, bluetongue, leptospirosis
Bovine embryos	Contact	Cattle	Reproductive	Direct	FMD
Beef	Scraps fed	Swine	Gastro-intestinal	Vehicle-borne	FMD
Beef	Consumed	Man	Gastro-intestinal	Vehicle-borne	Cysticercosis
Beef	Scraps fed	Dog	Gastro-intestinal	Vehicle-borne	Echinococcosis
Swine	Contact	Man	Various	Direct	Leptospirosis, Q fever, rabies, porcine brucellosis
Swine	Contact	Swine and other animals	Various	Direct, vector-borne	All Lists A and B diseases affecting swine
Pork	Scraps fed	Swine	Gastro-intestinal	Vehicle-borne	FMD, SVD, ASF, HC, trichinellosis, porcine cysticercosis
Pork	Consumed	Man	Gastro-intestinal	Vehicle-borne	Porcine cysticercosis, trichinellosis
Milk and milk products	Consumed	Man	Gastro-intestinal	Vehicle-borne	Q fever, brucellosis, tuberculosis
Milk and milk products	Fed	Swine	Gastro-intestinal	Vehicle-borne	FMD, Q fever, brucellosis, tuberculosis
Cattle hides	Contact	Man	Skin	Direct	Anthrax
Cattle hides	Via man	Cattle and other animals	Gastro-intestinal	Vehicle-borne	FMD, anthrax
Animal feeds, cattle blood and meat meals, horn and hoof meals, fats and oils	Fed directly	Cattle, sheep, goats, swine	Gastro-intestinal	Vehicle-borne	FMD, anthrax, BSE
Milk replacers	Fed directly	Cattle, sheep, goats, swine	Gastro-intestinal	Vehicle-borne	FMD

FMD: foot and mouth disease
SVD: swine vesicular disease
ASF: African swine fever
HC: hog cholera
BSE: bovine spongiform encephalopathy

For products, the diseases which are transmitted only by direct transmission (contagious bovine pleuropneumonia, rinderpest, Rift Valley fever, leptospirosis, rabies) and only by vectors (bluetongue, heartwater, anaplasmosis, babesiosis) have a PDE approaching zero. The vector-borne diseases can be introduced into an importing country if the commodity is live cattle and if competent vectors exist at the time of importation, or if the commodity is a product (e.g. fresh hides) infested with living and infected ticks.

Echinococcosis, cysticercosis and trichinellosis may be transmitted via vehicle-borne transmission in which humans and animals consume carcass meats and organs infected with viable parasites. Live animals which are imported may be the source of these agents after slaughter.

The many scenarios which exist within the importing country for the exposure of a commodity and agents contained in the commodity must be elaborated for any risk assessment. The existence of potentially multiple agents in any commodity adds to this complexity. However, if the PAE is essentially zero for some diseases and the PDE is zero for other diseases, the complexity diminishes.

Using historical importation statistics

Multiple scenarios exist for the exposure of pork and the agent of trichinellosis to both humans and swine, as well as wild fauna, through the importation of pork from a country infected with swine trichinellosis. The exposure of viable *Trichinella spiralis* parasites to man is related to customs and cultural practices of the importing country with regard to the cooking of pork for human consumption. The frequency of consumption of inadequately-cooked pork by the human population in general, or by particular ethnic and cultural groups within a country, is often not known.

However, there may be historical information on the number of human cases of trichinellosis associated with pork consumption, the quantity of carcass pork imported from another country, and the approximate level of trichinellosis infection in the swine population of the exporting country. If no cases of human trichinellosis were observed over the past 10 years, during which time 20 million kg of frozen carcasses and half-carcasses of pork were imported annually from Country A, both the PDE and the URE are minimal. This is determined by considering that 50 kg represents one AIU and that, therefore, over the 10 years approximately 4 million AIUs of the product were imported. Of these, approximately 160,000 were infected with trichinellosis, based on Country A reporting an enzootic level of trichinellosis in swine and the prevalence level to which this correlates from Table II (4×10^{-2}). A mean frequency of exposure can then be estimated, using the beta statistical distribution (83) with the following parameters:

$a_1 = x + 1$ and $a_2 = n + 1 - x$.

The mean of the above distribution is calculated as follows:

$$\mu = \frac{x+1}{n+2}.$$

The standard deviation is equal to:

$$\sigma = \frac{1}{n+2}\sqrt{\frac{(x+1)(n+1-x)}{(n+3)}}.$$

The "most likely" value for the above beta distribution is the so-called "mode" = x/n. Therefore, if one wants to approximate the beta distribution by a triangular distribution (83), the three parameters for the latter would be as follows:

if $x > 0$ $\quad a = \max(0, \mu - 3\sigma)$, $b = x/n$ $\quad$ and $c = \mu + 3\sigma$

if $x = 0$ $\quad a = \max(0, \mu - 3\sigma)$, $b = \frac{x+1}{n+2}$ and $c = \mu + 3\sigma$.

In this example, where $x = 0$ and $n = 160{,}000$, the beta distribution parameters compute a mean of 6.3×10^{-6} and a standard deviation of 6.3×10^{-6}. Since the number of human cases of trichinellosis is zero, the minimum, most likely and maximum parameters for the triangular distribution are 0, 6.3×10^{-6} and 2.5×10^{-5}, respectively. Converting the triangular input into a cumulative distribution function (80) using the Latin Hypercube simulation of @Risk, we obtain a 99% probability that the frequency of exposure and human infection is less than 2.3×10^{-5}. This gives the best estimate of the URE, although it is expressed as a probability of a frequency rather than a simple probability value.

Using information on animal and human population statistics and practices

The exposure of swine to viable *Trichinella spiralis* parasites may involve a number of scenarios, such as the following:

a) the discarding of uncooked meat scraps from households to swine

b) the consumption of uncooked pork at garbage disposal sites by either domestic or feral swine

c) the consumption of uncooked pork in swine-rearing operations which rely on the feeding of hotel and restaurant food waste.

Some importing countries may have complete compliance with animal health regulations regarding exclusion of swine from garbage disposal sites, and the licensing and adequate cooking of food waste in garbage-feeding swine herds. If this is the case, these scenarios do not have to be considered. In other countries, the control of these activities may be limited and the frequency of exposure of swine to uncooked pork through these scenarios is completely unknown. As with the human exposure scenario for trichinellosis detailed above, the most appropriate means of answering this is through historical importation information. One can even consider such information from other importing countries which have similar exposure scenarios and national animal health compliance levels, and similar customs and cultural practices.

For the scenarios involving the feeding of meat scraps to swine, a probability could be based on the division of the total number of farms reporting the presence of swine by the total number of households in the country, and multiplying this by the proportion of producers which could be expected to feed household table scraps to swine. Here, a farm is assumed to represent a household, although this probably exaggerates the number of households which rear swine in any country.

The following provides an illustration of this method, using actual population statistics. In Canada, there are 10,018,265 households, of which 2,129,365 are designated as rural households. A rural household is considered to be any household outside an urban area. An urban area is defined as a continuous built-up region with a population concentration of greater than 1,000 and a population density of greater than 400 per km^2 (1991 Census Data, Statistics Canada).

A total of 29,592 farms report owning one or more pigs (1991 Census of Agriculture, Statistics Canada). If each farm is considered to be a household, the proportion of Canadian households which rear swine is 0.003. The upper limit of the proportion of producers which would be expected to feed household table scraps to swine could be taken as the proportion of the number of small swine producers to the total number of swine producers. The agriculture census data for Canada indicate that there are seven herd size groupings, of which the smallest is 1-77 swine. There are 14,907 farms in this group (1991 Census of Agriculture, Statistics Canada). As a proportion of the total number of farms reporting the presence of swine, this represents 0.50. Therefore, the PDE for this specific scenario in Canada is $0.003 \times 0.50 = 1.5 \times 10^{-3}$.

For the other scenarios, the means of estimating the probabilities has to be considered. If the above probability estimate for the exposure scenarios through swine appears reasonable, similar methods could be used, based on livestock and human population census data. Obviously, these probability estimates of domestic exposure will be different for each country. Different scenarios will exist, and livestock and population census data will give different proportions.

MacDiarmid (72) presented a mathematical expression employed by the Australian Bureau of Rural Resources in an assessment of the risk associated with the importation of pork from countries infected with transmissible gastroenteritis (TGE) of pigs. In this expression, the probability (T) of TGE being introduced is related to the probability (p) that a piece of pork contains the virus and the number of occasions (n) that raw pork is fed to pigs. The expression can be stated as follows:

$T = 1 - (1 - p)^n$

and for $T < 1/2,500$, $T = pn$.

Here, $p = ivs$ and $n = hmft$.

where:

- i is the probability that a pig was infected with TGE virus at the time of slaughter
- v is the proportion of infected pork still containing infective virus when marketed
- s is the proportion of imported pork among all the fresh pork sold
- h is the number of small pig herds in Australia
- m is the number of unprocessed pork meals eaten per year
- f is the proportion of pig farmers who feed scraps to pigs
- t is the proportion of occasions on which the scraps contain raw pork.

Therefore, T represents the URE.

Whether the estimation of the PDE or URE is conducted through historical importation statistics or using a computation based on animal and human population statistics, the facts supporting the method must be fully documented. The use of importation statistics in which there was no occurrence of disease represents fairly concrete information on the safety of the importation, providing that sufficient data are available. When these data are lacking or insufficient, other methods similar to the above may be used to obtain the probabilities associated with each scenario. In general, only the most likely scenario is investigated in such a manner. If an unacceptable URE is obtained, no other scenarios need to be elaborated, as the importation would be rejected; however, if the most likely scenario gives rise to a low URE, all scenarios for that commodity/agent combination should be evaluated.

CONCLUSION

Summary of steps for the risk assessment model

The steps used in the model may be summarised as follows:

a) For OIE List A diseases except bluetongue:

i) Obtain the most recent twelve months of statistics on the number of outbreaks from the OIE publications *World Animal Health* or *Bulletin*.

ii) Obtain the population statistics for the particular species from *World Animal Health*. Compute the AHS by dividing the animal population by the number of herds for the species concerned.

iii) Obtain the ADI (in days) of the OIE List A diseases from Table I of this paper. Transform the units of the ADI into years by dividing the number of days by 365.

iv) Obtain the calculated prevalence using expression 3 above.

b) For OIE List B diseases and for bluetongue:

i) Obtain the status of the disease (exceptional, low sporadic, enzootic or high) in the occurrence column of *World Animal Health*. Depending on the outcome of the evaluation of the Veterinary Services, assign either the exceptional, low sporadic, enzootic or high level of occurrence to the following three disease occurrence designations:

- suspected but not confirmed
- serological evidence and/or isolation of causative agent; no clinical disease
- disease exists; distribution and occurrence unknown.

ii) Obtain from Table II of this paper the upper prevalence value for the disease occurrence obtained in *b) i)* above, i.e. the assigned prevalence.

c) Depending on the disease risk, employ either the calculated prevalence or the assigned prevalence as the CF1 in expression 2 above.

d) Be aware of any recent changes in the disease status of the exporting country by referring to the weekly OIE publication *Disease Information*.

e) Determine the CF2 relating to the properties of the commodity. Where the processing of a product effectively eliminates the disease agent, an extremely small probability value (e.g. 10^{-8}) can be employed. Where there is little influence, a probability value of 1.0 can be employed.

Document, with literature references, the determinants considered and the value employed for the CF2.

f) State the number of AIUs, based on the description of the importation.

Document, for product importations, the basis of the selection of a weight equivalency.

g) Compute the PAE (expression 2) based on the two probabilities, CF1 and CF2, and the number of AIUs. This expression gives the probability that at least one AIU of the importation is infected.

h) Determine the PDE, based on the epidemiology of the disease, the nature of the commodity, the relevant human and animal demographics and population statistics, customs and cultural practices, animal health legislation and compliance levels, and statistics on the quantity of historical importation without disease.

i) Calculate the URE (expression 1 above).

j) Evaluate the consequences (economic, social, political, environmental) associated with the importation.

k) Present both the URE(s) and the associated consequences to the decision-maker.

Note: A multiple species disease may exist and be reported in another species. In this situation, an assessment of the Veterinary Services and the surveillance and animal health monitoring programmes may satisfy the importing country that the absence of the disease in the species of concern is a fact rather than a reporting deficiency.

Present and future models

The risk assessment model uses the available animal health and disease statistics to assess the risks associated with the importation of a specific quantity of animals or animal products. The correlation of the nominal level of disease occurrence reported for List B diseases and bluetongue may not be valid at present. Detailed guidelines do not exist for the reporting of the level of occurrence of these diseases, and until such guidelines become available this will remain a major deficiency of the model.

For the reporting of List A diseases, the definition of "outbreak of disease" for the OIE reporting system indicates that more than one herd could be involved in a single outbreak. This risk assessment model uses the definition of "herd outbreak", which is more useful, as it portrays the extent of the disease. The present reporting system definition is useful epidemiologically. This difference in definitions represents another deficiency of the model.

Although this model uses prevalence of infection in the entire population of the exporting country (based on the statistics of the OIE reporting system), it is envisaged that prevalence of infection in herds and regions of a country may be future statistics of the reporting system and a model appropriate for these data would therefore be required. The present model benefits an exporting country which has almost eradicated a disease. That is, it assesses the risk of importation based on the prevalence rather than just the presence of the disease. In future models based on the prevalence of infection in herds, this same exporting country would be in a much better standing for the export of commodities. Disease does localize in herds and in regions, and it is somewhat unfair to imply that the population at risk is that of the entire country. Nonetheless, the model has to use whatever data are available and, more importantly, provide security for the importing country.

This risk assessment permits the decision-making aspect of risk management to proceed. Foremost, the risk assessment documents the basis for a decision and provides for a scientific exchange between regulatory officers of both the importing and exporting countries.

Point estimates are obtained with this risk assessment model. An importing country may wish to conduct a sensitivity analysis on the computation of the URE. This may involve utilizing a range of CF1 and CF2 values as well as a range of variables in the estimation of the PDE.

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MODÈLE D'ÉVALUATION DES RISQUES DE MALADIE LIÉS À L'IMPORTATION D'ANIMAUX ET DE PRODUITS D'ORIGINE ANIMALE. – R.S. Morley.

Résumé *: L'auteur présente une modèle mathématique simple destiné à évaluer les risques de maladie liés à l'importation d'animaux et de produits d'origine animale. Ce modèle repose sur les statistiques de santé animale communiquées par les Pays Membres de l'Office international des épizooties (OIE), et fournit une méthode structurée permettant d'exploiter les informations disponibles sur une importation donnée. Le modèle peut intégrer toutes sortes de paramètres, quel qu'en soit le nombre, à savoir la situation zoo-sanitaire du pays exportateur, les animaux ou produits d'origine animale échangés, les propriétés de l'agent pathogène et l'épidémiologie de la maladie. Tous les risques de maladie peuvent être pris en considération. Ce modèle est illustré par des exemples d'importation de bovins, porcins et produits dérivés.*

MOTS-CLÉS : Evaluation des risques - Importation d'animaux - Maladies des Listes A et B de l'OIE - Modèle - Prévalence.

*
* *

MODELO DE EVALUACIÓN DE RIESGOS ZOOSANITARIOS ASOCIADOS A LA IMPORTACIÓN DE ANIMALES Y DE PRODUCTOS PECUARIOS. – R.S. Morley.

Resumen: *El autor presenta un modelo matemático simple, destinado a evaluar los riesgos de enfermedad asociados a la importación de animales o de productos pecuarios. Este modelo se basa en las estadísticas de sanidad animal comunicadas por los Países miembros de la Oficina internacional de epizootias (OIE), y ofrece un método estructurado, que permite explotar las informaciones disponibles acerca de una importación determinada. El modelo puede integrar cualquier cantidad de parámetros, como los relacionados con la situación zoosanitaria del país exportador, los animales o productos pecuarios objeto del intercambio, las propiedades del agente patógeno y la epidemiología de la enfermedad. Todos los riesgos de enfermedad pueden tenerse en cuenta. Se ofrecen ejemplos ilustrativos de este modelo, aplicados a la importación de bovinos, porcinos y productos derivados.*

PALABRAS CLAVE: Enfermedades de las Listas A y B de la OIE - Evaluación de riesgos - Importación de animales - Modelo - Prevalencia.

*
* *

Appendix

ANIMAL HEALTH STATUS AND DISEASE CONTROL METHODS

COUNTRY: Country A — Year: 1992

	Livestock population	Number of herds
Bovine	23212325	85650
Buffalo	...	...
Ovine	5800300	22150
Caprine	83450	9175
Equine	405680	70190
Swine	26850250	72375
Avian	115326800	83975
Hare/rabbits (in farms)	343235	10815
Fish (in farms)	...	...
Camel	...	...
Bees (apiaries)	888650	45670

DISEASES IN O.I.E. LISTS A AND B	SPE	EPIZOOTIOLOGY				DISEASE CONTROL				Notes
		OCCUR.	NUMBER OF			CONTROL MEASURES	NUMBER OF ANIMALS			No.
			Outbreaks	Cases	Deaths		Slaughtered	Vaccinated	Treated	
LIST A DISEASES										
Contagious bov pleuropneumonia		(+)	10	200	200	* Pn Q S	1000			
Hog cholera		+	86	890	750	* Pn Q S	4500			
LIST B DISEASES										
Multiple species										
Anthrax	bov	(+)()	5	41	41	* Pn Qi Sp V	0	1250	0	
	sui	-				*				
Aujeszky's disease	bov	0000				* Qf				
	sui	(+)	12	950	540	* Pn Q S	1345			
Echinococcosis/hydatidosis	bov	(+)								
	sui	(+)								
Heartwater		0000				Qf				
Leptospirosis	bov	++				T tv V				
	sui	++				T tv V				
Q fever		+				tv				
Rabies	bov	(+)		1213	1213	* Pn Qi V				
	sui	(+)		15	15	* Pn Qi V				
Paratuberculosis	bov	+				Pn tv				
Screwworm (*C. hominivorax*)		0000				Qf				
Cattle										
Anaplasmosis		(+)	3	35	25	* Pn Q S	245			
Babesiosis		0000				Qf				
Bovine brucellosis (*B. abortus*)		(+)	2	55	0	* Pn Q S te V	345	63780	0	
Bov. genital campylobacteriosis		+				T tv				
Bovine tuberculosis		(+)	1	5	0	* Pn Q S te	1250	0	0	
Cysticercosis (*C. bovis*)		(+)	16	38	0	* Pn Qi Sp				
Dermatophilosis		-								
Enzootic bovine leukosis		++				tv				
Haemorrhagic septicaemia		-								
Inf bov rhinotracheit (IBR/IPV)		++				tv V				
Theileriosis		0000								
Trichomonasis		-				T tv				
Trypanosomiasis		0000								
Bovine malignant catarrh		-								
Bov spongiform encephalopathy		0000				*				
Pigs										
Atrophic rhinitis of swine		++				tv V				
Cysticercosis (*C. cellulosae*)		-				te				
Porcine brucellosis (*B. suis*)		0000				* Qf				
Transmissible gastroenteritis		+				tv V				
Trichinellosis		++	1	15		* te	25			

CODES

Animal group

api	bees
avi	avian
bov	bovine
buf	buffalo
can	canine
cap	caprine
cml	camel
equ	equine
fau	wild fauna (vertebrates)
fel	feline
lep	hare/rabbit
ovi	ovine
pel	fur-bearing animals (in farms)
pis	fish
sui	swine
c/f	canine/feline
o/c	ovine/caprine
etc	other

Disease occurrence

0000	Never reported
-	Not reported
year	Year of last occurrence
?	Suspected but not confirmed
(+)	Exceptional occurrence
+	Low sporadic occurrence
++	Enzootic
+++	High occurrence
+?	Serological evidence and/or isolation of causative agent, no clinical disease
+..	Disease exists; distribution and occurrence unknown
()	Confined to certain regions
)(	Ubiquitous
!	Recognised in country for the first time
<=	Only in imported animals (quarantine)
...	No information available

Disease control

Cn	Control of non-vertebrate vectors
Cr	Control of wildlife reservoirs
P	Prohibition of import from infected countries
Pa	Control programme for only some areas of the country or certain types of breeding
Pn	Control programme for the whole country
Q	Quarantine, movement control and other precautions at frontier and inside the country
Qf	Quarantine and other precautions at frontier
Qi	Quarantine measures and movement control inside the country
S	Stamping-out policy
Sp	Modified stamping-out policy
T	Treatment
te	Testing
tv	Voluntary testing
V	Vaccination
Vp	Vaccination prohibited
*	Notifiable disease

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Risk analysis and the importation of animals and animal products

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Summary: *Importation of animals or animal products cannot take place without some element of risk. Risk analysis is a blend of art and science and is a tool intended to provide decision-makers with an objective, repeatable and defensible assessment of the risks posed by a particular import proposal. Risk analysis comprises risk identification, risk assessment, risk management and risk communication. Examples are presented of risk analysis involving anthrax in green hides, slow virus diseases and sheep embryos, and Office International des Epizooties List A diseases and embryos. The author proposes that, by sharing methodologies, quarantine services should be able to harmonise approaches to the problem of risk analysis.*

KEYWORDS: Anthrax – Embryo transfer – List A diseases – Maedi-visna – Quarantine – Risk analysis – Risk assessment – Scrapie.

INTRODUCTION

Risk analysis is a tool intended to provide decision-makers with an objective, repeatable and defensible assessment of the risks posed by a particular import proposal. The process of risk analysis can be made transparent so that interested parties in the importing country or authorities in the exporting country can, if required, be provided with the documented basis on which the proposal is accepted or declined.

When analysing the risks associated with a proposed importation of animals or animal products, it must be remembered that such imports cannot be made without some element of risk. The benefits of the imports often accrue to only a relatively small group of people, usually the entrepreneurs, initial importers and distributors of the new genetic material (1). The risks, on the other hand, are borne by a much broader group which includes all livestock owners whose animals could be infected with an exotic disease agent as well as the general public, who may be expected to bear the cost of containing and eradicating an outbreak of exotic disease. For these reasons, a risk analysis may include a cost/benefit analysis of the proposed importation. The policy of the New Zealand Ministry of Agriculture is that every citizen has the right to import unless the risk to agricultural security precludes importation. Such a policy presupposes that the quarantine service is charged with making judgements about the risks, and therefore the costs which may be imposed on the agricultural community, but does not sit in judgement on what are commercial decisions.

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